RANGE RULE RISK METHODOLOGY
(INTERIM)

STREAMLINED RISK EVALUATION

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CONTENTS

TABLES

Table

FIGURES

Figure

ACRONYMS AND ABBREVIATIONS

ASR	Archives search report
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
DNR	Department of Natural Resources
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DRE	Detailed risk evaluation
EPA	U.S. Environmental Protection Agency
ERAGS	Ecological Risk Assessment Guidance for Superfund
MEI	Most exposed individual
NAS	National Academy of Sciences
NAVEODTECHDIV	Naval Explosive Ordnance Disposal Technology Division
QRE	Qualitative risk evaluation
RAGS	Risk Assessment Guidance for Superfund
RCRA	Resource Conservation and Recovery Act
R3M	Range Rule risk methodology
SRE	Streamlined risk evaluation
USACE	U.S. Army Corps of Engineers
USAEC	U.S. Army Environmental Center
USATCES	U.S. Army Technical Center for Explosives Safety
UXO	Unexploded ordnance

VARIABLES

A	Total area available for receptor activity
A_j	Total area available for intrusion by activity j
A_{MEI}	Total area available for MEI receptor activity
a	Area affected by receptor
a_{MEI}	Area affected by MEI receptor
AD	Activity duration
AR	Activity rate
C	Consequences of accident, or consequences of UXO detonation
C_{max}	Highest C value associated with UXO in A_{MEI}
ED	Exposure duration
EF	Exposure frequency
Di	Energy released from a detonation of UXO type i
E_a	Enery of Activation
E_j	Enery imparted to a UXO by receptor activity type j
E_{min}	Minimum energy required to initiate a detonation in UXO type i
i	UXO category
j	Activity category
LR	Lifetime risk
LT	Lifetime
n	Number of UXO within a certain area
n_j	Number of UXO within maximum depth for activity j
NEW	Net explosive weight
P	Probability of accident
P_D	Conditional probability of detonation
$P_{D,max}$	Highest P_D value associated with UXO in A_{MEI}
P_E	Probability of UXO encounter
PL	Path length
PW_{def}	Default path width
R	Risk
R_{MEI}	Risk estimate for MEI receptor
W_j	Maximum energy a receptor type j can with stand without injury
ε	Range-specific correction factor
γ	Activity-specific correction factor
λ	UXO density
λ_j	Depth-specific UXO density for activity j
λ_{MEI}	UXO density estimate for MEI receptor

1.0 INTRODUCTION

The U.S. Department of Defense (DoD) Proposed Range Rule (1997) identifies a process for evaluating response actions at closed, transferring, and transferred military ranges. The proposed Range Rule states that DoD will develop a methodology to assess potential risks at these ranges. DoD has prepared this Range Rule Risk Methodology (R3M) Streamlined Risk Evaluation (SRE) methodology document to meet the DoD Range Rule requirement for a risk methodology.

1.1 BACKGROUND

DoD has proposed a Range Rule (DoD 1997) that identifies a process for evaluating appropriate response actions on closed, transferred, and transferring ranges. Response actions shall address safety, human health, and the environment. The Range Rule contains a five-part process that is not inconsistent with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and is tailored to the special risks posed by military munitions and military ranges. This five-part process includes (1) range identification, (2) range assessment, (3) range evaluation, (4) recurring reviews, and (5) range close-out. To satisfy this process, DoD has developed a three-component risk evaluation methodology (R3M) that includes qualitative risk evaluation (QRE), SRE, and detailed risk evaluation (DRE) methodologies. The Range Rule process and the way it relates to the risk evaluation methodologies are summarized in Figure 1.

DoD recognizes the urgent need to develop a risk assessment model to address the special risks posed by military munitions and military ranges. Such a model must incorporate, to the maximum extent possible, the risk assessment models developed by the U.S. Environmental Protection Agency (EPA) to assess acute and chronic risks posed by releases at sites regulated under CERCLA and the Resource Conservation and Recovery Act (RCRA) (DoD 1997). The R3M represents DoD's effort to develop an unexploded ordnance (UXO) explosives safety risk model. It first qualitatively estimates range-specific explosives safety risks using a QRE during the Range Rule's range assessment phase. Ranges that are not screened out of the R3M after the QRE are then evaluated using quantitative SRE or DRE procedures. The SRE is a continuation of the Range Rule's range assessment phase, and the DRE is part of the Range Rule's range evaluation phase. The QRE and DRE methodologies are presented in separate documents. This document presents the SRE methodology.

The special risk associated with military munitions and military ranges can be grouped into two general categories: (1) explosives safety risks associated with physical forces generated by detonating UXO and (2) chemical risks associated with other constituents.

Explosives safety risks exist because receptors can come into contact with UXO present on a range. If UXO detonates when it is encountered by a receptor, it can cause immediate injury or death. EPA guidance does not specify how explosives safety risks should be addressed; this document describes the second of three steps that DoD is proposing to address these risks.

Chemical risks associated with other constituents exist on ranges, primarily from a release or a potential release of these other constituents. When releases occur, human and ecological populations could potentially be exposed to other constituents through contact with contaminated soil, inhalation of airborne chemicals, or ingestion of contaminated groundwater or other affected media, including the food chain. DoD and EPA believe that existing guidance should be used to evaluate potential risks to human health and the environment from releases of other constituents. Primarily, this existing guidance includes EPA's Risk Assessment Guidance for Superfund (RAGS) (EPA 1989) and EPA's Ecological Risk Assessment Guidance for Superfund (ERAGS) (EPA 1996). It is possible that all risk assessment or evaluation protocols – R3M, RAGS, and ERAGS – could be employed at the same range, each providing distinct risk estimations.

1.2 PURPOSE OF THE STREAMLINED RISK EVALUATION

The purpose of the SRE is to augment data obtained during the QRE and to provide a worst-case, quantitative explosives safety risk estimate for receptors at ranges containing UXO. At ranges or range sectors for which the QRE revealed qualitative risk, the SRE will provide a measure of that risk. The outcome of the SRE is a deterministic explosives safety risk estimate for the receptor that is most exposed to range UXO-related risk – the most exposed individual (MEI).

R3M results are only part of the information used by risk managers to determine appropriate actions for ranges or range sectors. Similar to EPA's CERCLA program, several types of information are used in this decision-making process, and the risk assessment provides a major portion of this information.

However, other data are also considered in making final decisions regarding ranges or range sectors, including political and community-based information.

1.3 DEFINITIONS

Several terms commonly used in the context of the methodology are presented below to clarify the scope of the SRE; the definitions are identical to those contained in the proposed DoD Range Rule.

Range Rule Terms

- Accelerated Responses (ARs). Any readily available, generally used, reliable, and easily implemented methods of addressing the risk posed by military munitions, UXO, or other constituents at military ranges. ARs may be fully protective in and of themselves.

- Active Range. A military range that is currently in service and is being regularly used for range activities.

- Closed Range. A military range that has been taken out of service as a range and that either has been put to new uses that are incompatible with range activities or is not considered by the military to be a potential range area. A closed range is still under the control of a DoD component.

- Federal Land Manager. Federal agencies having or clearly anticipated to receive jurisdiction, custody, or control over the property.

- Inactive Range. A military range that is not currently being used, but that is still considered by the military to be a potential range area, and that has not been put to a new use that is incompatible with range activities.

- Military Munitions. All ammunition products and components produced or used by or for DoD or the U.S. Armed Services for national defense and security, including military munitions under the control of DoD, the U.S. Coast Guard, the U.S. Department of Energy (DOE), and National Guard personnel. The term military munitions includes: confined gaseous, liquid, and solid propellants, explosives, pyrotechnics, chemical and riot control agents, smokes and incendiaries used by DoD components, including bulk explosives and chemical warfare agents, chemical munitions, rockets, guided and ballistic missiles, bombs, warheads, mortar rounds, artillery ammunition, small arms ammunition, grenades, mines, torpedoes, depth charges, cluster munitions and dispensers, demolition charges, and devices and components thereof. Military munitions do not include wholly inert items, improvised explosive devices, and nuclear weapons, nuclear devices, and nuclear components thereof. However, the term does include non-nuclear components of nuclear devices, managed under DOE's nuclear weapons program, after all required sanitization operations under the Atomic Energy Act of 1954, as amended, have been completed.

- Military Range. A designated land or water area set aside, managed, and used to conduct research on, develop, test, and evaluate military munitions and explosives, other ordnance, or weapon systems, or to train military personnel in their use and handling. Ranges include firing lines and positions, maneuver areas, firing lanes, test pads, detonation pads, impact areas, and buffer zones with restricted access and exclusionary areas. The definition of a military range does not include airspace, or water, or land areas underlying airspace used for training, testing, or research and development where military munitions have not been used.

- Other Constituents. Other constituents are potentially hazardous chemicals that are located on or originate from closed, transferred, or transferring ranges and are released from military munitions or UXO, or resulted from other activities on military ranges. Other constituents may be subject to other statutory authorities, including, but not limited to, CERCLA (42 U.S.C. 9601, *et seq*.) and RCRA (42 U.S.C. 6901, *et seq*.).

- Transferred Range. A military range that is no longer under military control and has been leased, transferred, or returned to another entity, including federal entities. This includes a military range that is no longer under military control but that was used under the terms of a withdrawal, executive order, special-use permit or authorization, right-of-way, public land order, or other instrument issued by the federal land manager.

- Transferring Range. A military range that is proposed to be transferred from DoD to another federal entity or disposed of by conveying title to a nonfederal entity. This includes a military range that is used under the terms of a withdrawal, executive order, special-use permit or authorization, right-of-way, public land order, or other instrument issued by the federal land manager. An active range shall not be considered to be a "transferring range" until the transfer is imminent.

- Unexploded Ordnance. Military munitions that have been primed, fused, armed, or otherwise prepared for action, and have been fired, dropped, launched, projected, or placed in such a manner as to constitute a hazard to operations, installation, personnel, or material and remain unexploded either by malfunction, design, or any other cause.

Other terms commonly used to describe military ranges are presented below. These definitions are based on several DoD guidance documents and are presented to assist R3M users in describing ranges as the risk analysis is conducted.

R3M Specific Terms

- Buffer Zone. The area on a range extending beyond an impact area to provide a safety zone to contain ricochets, blast, and fragmentation from exploding ordnance.

- Firing and Release Positions. The area on a range from which military munitions are employed (e.g., fired, dropped, placed, launched).

- Impact Area. The area on a range within the limits of which all ordnance is intended to impact and/or detonate. An impact area includes the area containing the target, plus the immediate area around the target, to contain rounds that miss that target.

- Initiating Force. The forces that when imposed on an item of UXO, can result in a detonation of that UXO. These forces include temperature, shock, friction, magnetism, static or lightning, and electromagnetic radiation.

- Safety Fan. The area on a range surrounding the impact area, buffer zone, and firing and release points that is designed to contain munitions that fail to hit within the impact area.

- Sector. A homogeneous, contiguous area located within a range. The sector is homogeneous with respect to terrain, future land use, and expected ordnance density.

- Training and Maneuver Areas. Other range areas historically used for training or maneuvers, but not used as impact areas, buffer zones, safety fans, or firing and release positions.

2.0 GENERAL APPROACH

Since 1990, at least three general UXO explosives safety risk assessment and site ranking approaches have been developed for DoD by various military agencies; pertinent information about these approaches is summarized below:

- The U.S. Army Corps of Engineers (USACE) developed the Ordnance and Explosive Waste Site Risk Mitigation Prioritization methodology. The model, which is known as OECert, was developed as an engineering model to predict public risk at ordnance sites (QuantiTech 1994; Riggs and Fanning 1996).

- The U.S. Army Environmental Center developed a UXO risk assessment methodology for site-specific application at Fort George G. Meade, Maryland. It is known as the Fort Meade Model (Hill and others 1996; SAIC 1995).

- The Naval Explosive Ordnance Disposal Technology Division (NAVEODTECHDIV) developed a general UXO risk assessment methodology for application at military ranges containing UXO. It is known as the NAVEODTECHDIV Model (PRC EMI 1995; Mulvihill and others 1996).

The methods and underlying assumptions of each of these models were considered in the development of the R3M.

2.1 OVERVIEW OF THE RANGE RULE RISK METHODOLOGY

The QRE is the first of three methodologies for evaluating explosives safety risks posed by military ranges. It qualitatively evaluates the variables critical to UXO-related risk (see Section 2.2) and estimates the qualitative degree of UXO risk to which receptors may be exposed. The worst-case assumptions used in the QRE make it the most protective of the QRE, SRE, and DRE.

Risk attributed from other constituents is not directly evaluated during the QRE, SRE, or DRE. If data gathered during these evaluations indicate that other constituents may be present on a range, they should be addressed and evaluated using established methodologies (such as the methods developed for use in implementation of CERCLA or RCRA). In such cases, separate risk assessments are likely pursued, focused on these other constituents and performed in conjunction with the R3M process. The remaining discussion focuses only on evaluating explosives safety risk.

Considering the results of a QRE, several risk management options could be recommended: (1) further evaluation using the SRE methodology, (2) further evaluation using the DRE methodology, or (3) range close-out. Because the QRE methodology is a tool based on worst-case assumptions, the risk manager can use QRE results to support range close-out decisions. However, based on other considerations, the risk manager may choose to further evaluate the range using the SRE or DRE methodologies.

The SRE is the second risk evaluation tool in the R3M process. It takes a screening-level risk assessment approach and estimates the maximum quantitative degree of UXO risk to which receptors may be exposed. An MEI receptor is identified, and risks to the MEI are evaluated deterministically, using worst-case assumptions and data. Considering the SRE results, the risk manager may decide that an AR or site-specific removal action must be undertaken, a DRE must be completed, or no further action is required. Range sampling activities are considered to be a component of the SRE; the data gathered for the SRE help delineate the range and describe UXO present on the range.

The DRE is the final R3M risk evaluation tool and is a comprehensive assessment that incorporates range sampling and characterization results from activities that must be conducted before the SRE or DRE are performed. The DRE quantifies deterministic and probabilistic risk from UXO, and it assists the risk manager in determining the adequacy of ARs or determining the necessity of site-specific response actions.

The Range Rule identifies how AR alternatives and site-specific response actions shall be evaluated, using available information. The evaluation assesses how those actions would address the nine criteria, as set forth in the National Contingency Plan. Additionally, the Range Rule defines the stakeholder involvement requirements in the AR and site-specific response selection process. As appropriate, the R3M components (QRE, SRE, and DRE) each should be used to facilitate the AR and site-specific response action evaluations and the decision-making process.

The R3M is designed to estimate risk associated with involuntary UXO encounters and UXO encounters associated with UXO-related site work. Risk associated with unauthorized voluntary exposures, such as souvenir collecting and scavenger hunting, may or may not be fully estimated under the R3M framework. These exposures often include an additional risk that cannot be reliably modeled and is attributed to unauthorized handling or manipulation of the UXO. When considering worst-case assumptions, this additional risk (from handling UXO) may be included and subsequently will not affect the resulting risk estimate. However, when site-specific data are used in lieu of worst-case assumptions, the resulting risk estimates may not always include the additional risks posed by the unauthorized activity.

2.2 RISK ASSESSMENT VARIABLES

Risk is defined by the National Academy of Sciences (NAS) as the potential for adverse effects to an exposed population (NAS 1983). It is a function of the probability that an accident (or adverse situation) will occur within a certain time, as well as the accident's consequences to people, property, or the environment. Equation 1 summarizes this relationship.

$$R = f[P, C] \qquad \text{Equation 1}$$

where,

R	=	Risk
P	=	Probability of accident
C	=	Consequences of accident

In the United States, EPA has adopted general risk assessment methods for evaluating environmental and human health risks at hazardous and toxic waste sites that follow this basic relationship. This general risk assessment model is conducted through four basic steps: (1) hazard identification, (2) exposure assessment, (3) dose response modeling, and (4) risk characterization (NAS 1983; EPA 1989). Chemical dose response modeling is not directly applicable to UXO risk assessment. Chemical risk assessment assumes multiple exposures and additive effects; however, the explosives safety threat from UXO results from a single exposure, and it has a single effect – injury or death.

It is therefore necessary and appropriate to modify the chemical risk assessment process by replacing dose response modeling with UXO exposure response modeling. Assuming that UXO hazards exist at a range, the resulting risk assessment paradigm considers the following variables:

- Probability of UXO encounter (P_E)
- Conditional probability of detonation (P_D)
- Consequences of detonation (C)

For the R3M, risk (R) is defined as the product of P and C, and the probability of an accident (P) is further defined as the product of P_E and P_D. This relationship is summarized in Equation 2, and the variables are fully described in Sections 2.2.1 through 2.2.3.

$$R = P_E \cdot P_D \cdot C \qquad \text{Equation 2}$$

where,

R	=	Risk
P_E	=	Probability of UXO encounter
P_D	=	Conditional probability of detonation, given a UXO encounter
C	=	Consequences associated with UXO detonation

2.2.1 Probability of Unexploded Ordnance Encounter

To model risk at ranges containing UXO, it is necessary to divide the range into sectors, which are defined in Section 1.3 as homogeneous, contiguous areas located within a range. A sector is homogeneous with respect to terrain, future land use, and expected ordnance density. Sectors can be defined based on archive search report (ASR) results, past UXO characterization data, firing records, or other data that identify these range traits. After sectors are identified, they are evaluated separately.

The underlying assumption behind the following derivation of P_E is that UXO density is random. It is unlikely that this will be the case, but if ranges are divided into relatively homogeneous sectors with respect to UXO density, the approximation that UXO density is random can be made. With this approximation, the Poisson distribution can be used to characterize the spatial distribution of UXO. The probability that a receptor will encounter a specific UXO as he or she passes through the sector is then described in Equation 3.

$$P(\text{Encountering Specific UXO}) = \frac{a}{A}$$ Equation 3

where,

a = Area affected by receptor
A = Total area

The variables a and A are further defined in Sections 2.2.1.1 and 2.2.1.2.

The probability that a receptor will not encounter a specific UXO is described in Equation 4.

$$P(\text{Avoiding Specific UXO}) = 1 - \frac{a}{A}$$ Equation 4

If a particular number (n) of UXO are located within an area, the probability of avoiding all UXO while participating in an activity in the area is estimated by multiplying the probabilities of avoiding each UXO, as shown in Equation 5.

$$P(\text{Avoiding All UXO}) = \left(1 - \frac{a}{A}\right)^{n}$$ Equation 5

In cases where the number of UXO within an area is unknown, n must be estimated as the product of the UXO density (λ) and the total area (A). Equation 5 is then modified as follows:

$$P(\text{Avoiding All UXO}) = \left(1 - \frac{a}{A}\right)^{\lambda A}$$ Equation 6

Probability of encounter (P_E) is defined as the probability that a receptor will *not* avoid all UXO while participating in a given activity, as calculated using Equation 7.

$$P_E = 1 - \left(1 - \frac{a}{A}\right)^{\lambda A}$$ Equation 7

As discussed below in Section 2.2.1.2, a generalized approach for calculating *a* has been developed; this approach is expected to result in worst-case estimates of P_E. To better define a more realistic P_E, an activity-specific correction factor (γ) is applied to estimates of *a*, and the equation for calculating P_E is modified as follows:

$$P_E = 1 - \left(1 - \frac{\gamma a}{A}\right)^{\lambda A} \qquad \text{Equation 8}$$

Finally, existing models acknowledge that other, range-specific factors may affect P_E (PRC EMI 1995; QuantiTech 1994). For example, heavy vegetation or steep terrain may discourage certain activities but encourage others; such factors may indirectly affect P_E. In addition, UXO awareness may reduce P_E, because potential receptors may be more cautious when they enter areas they believe contain UXO. To account for these factors, a range-specific correction factor (ε) can be applied to the estimate of *a*, as shown in Equation 9; the correction factor is applied to *a*, because potential receptors will most likely modify their behavior depending on range-specific conditions.

$$P_E = 1 - \left(1 - \frac{\varepsilon \gamma a}{A}\right)^{\lambda A} \qquad \text{Equation 9}$$

Equation 9 is the general expression used to derive P_E within the R3M framework. This equation requires estimates for total area (*A*), area required by a receptor to participate in an activity (*a*), an activity-specific area correction factor (γ), a range features correction factor (ε), and estimated UXO density (λ).

The following sections discuss how each of these factors is determined. Figure 2 shows the family of P_E curves for a normalized range, which is defined as having unit *A* and varying *a* and λ. In Figure 2, the correction factors γ and ε are set to 1.

2.2.1.1 Total Area (*A*)

The total area (*A*) is the area in which a potential receptor may participate in an activity; it generally consists of one or more range sectors and may be bounded by areas that would prevent the activity from being conducted. As a result, it is critical that sector boundaries are defined appropriately before P_E is evaluated for any receptor. Sector boundaries are determined based on distinct UXO densities, former land use, current land use, natural boundaries, and possibly, receptor activity. For ranges that have been evaluated using the QRE, adequate data should exist to accurately define sector boundaries. When the SRE is conducted for each sector, *A* is the area of the sector of interest. For each receptor, *A* is evaluated as the area in which the receptor could potentially encounter UXO while participating in an activity.

2.2.1.2 Area Affected by Receptor (*a*)

The area affected by a receptor (*a*) is based on the receptor's use of the range. The existing models identified in Section 2.0 each identify specific activities to be evaluated; Table 1 summarizes activities identified by these existing models. Activities that will be evaluated using the SRE have not been determined for the universe of range sectors that must be evaluated; they should be selected on a sector-specific basis and based on current and reasonably expected future land use.

For the purpose of calculating *a*, activities are divided into two categories: (1) distance-based activities, where the receptor is assumed to travel along a certain distance and (2) site-based activities, where the receptor is assumed to use a certain site for the activity (see Table 1). It is important when defining *a* that the assessor look at the exposure area likely to be encountered and not focus strictly on the sector being evaluated. It is anticipated that *a* may often be a subset of the range sector. It is also possible that *a* could cross through several different sectors, especially for distance-based activities. Therefore, it is important to obtain thorough descriptions of activities and locations where they are expected to take place.

One of the major issues that must be considered when applying the R3M is current and future land use. The Range Rule (DoD 1997) states that reasonably expected future land uses should be considered, and the R3M should evaluate use, which might include recreational, agricultural, industrial, residential, or some combination of these uses.

2.2.1.2.1 Distance-Based Activities

For distance-based activities, it is convenient to assume a specific path width for all activities and to modify a using an activity-specific area correction factor (γ), which is described in Section 2.2.1.3. For the R3M, the default path width is defined as 3 feet. The area affected by the receptor (a) is then defined as the path length multiplied by the default path width, as shown in Equation 10.

$$a = PL \cdot PW_{def} \qquad \text{Equation 10}$$

where,

PL	=	Path length (feet)
PW_{def}	=	Default path width (3 feet)

Path length may be estimated based on site-specific data, such as the length of established jogging paths through portions of a range. Path length may also be estimated based on general data, such as the amount of time activity participants spend conducting the activity and the rate at which the activity is conducted. For example, regional data may suggest that joggers, on average, spend 30 minutes per day jogging at an average rate of 13,140 feet per hour. For these cases, Equation 11 can be used to estimate appropriate values for a.

$$a = AR \cdot AD \cdot PW_{def} \qquad \text{Equation 11}$$

where,

AR	=	Activity rate (feet/hour)
AD	=	Activity duration (hour)

The value for a, determined using Equation 10 or Equation 11, is then used to estimate P_E in Equation 9.

2.2.1.2.2 Site-Based Activities

For site-based activities, a is defined as the site area affected by the receptor, and the value of γ in Equation 9 is set to 1. Based on current and future projected land use, the value of a is determined by (1) estimating land use boundaries and (2) assuming that the entire area is available for receptor use each time the range or range sector is entered. For example, a farmer's site is defined as his or her entire field, because it is assumed that the entire field will be tilled. A camper is similarly assumed to use his or her entire campsite.

For some receptors, this method may provide a worst-case estimate of risk. The risk assessor may modify the site-based approach, if a distance-based approach is more applicable to a specific case.

2.2.1.3 Activity-Specific Area Correction Factor (γ)

As discussed in Section 2.2.1.2, *a* is calculated for a variety of distance-based activities using a default path width of 3 feet. However, this approach may overestimate *a* by as much as 2 orders of magnitude. For example, the calculation of *a* for a jogger assumes that a human "path" is a continuous area equal to the length of the route taken multiplied by a 3-foot path width. However, the receptor's feet only touch a small portion of this area. Assuming that an average human foot is a maximum of 12 inches long and 6 inches wide and that the average jogger places his or her foot on the ground once every yard of travel, the area within a square yard affected by the jogger is calculated to be 0.5 square feet. Yet using the default pathway width of 3 feet for the same yard of travel, *a* is calculated to be the entire square yard, or 9 square feet. When calculating γ, one must take into account that certain types of UXO may be highly sensitive, so the receptor's pressure zone may be larger than the receptor's footprint.

For distance-based activities, activity-specific area correction factors (γ) are calculated by assuming a unit "cell" of 1 square yard, or 9 square feet. The correction factor is then derived by dividing the actual area affected by a potential receptor participating in a particular activity by 9 square feet. For the jogging example described above, γ is derived as follows:

$$\gamma_{jogging} = 0.5 / 9.0 = 0.056$$

For area-based activities, the activity-specific correction factor is set to $\gamma = 1$.

If worst-case estimates of the actual area affected by each activity participant are used, γ will result in worst-case estimates of P_E. In other words, although activity participants may deviate from the estimated area affected (for example, if a jogger slows down for awhile or stops to rest), worst-case activity-specific γ values will prevent P_E from being underestimated.

2.2.1.4 Range Features Correction Factor (ε)

Existing risk methodologies identify range features that may affect UXO-related risk on military ranges, including sector slope, vegetation density, soil type, climate, and receptor awareness of the potential for encountering UXO.

Range features may commonly affect a receptor's potential exposure to UXO. For example, within a sector that is characterized by steep, rocky slopes, a hiker may contact more surface area than someone hiking at a relatively flat and smooth sector. If the activity-specific area correction factor γ is modeled for a hiker on flat, smooth field, the value of ε should exceed 1 for hikers on steep, rocky slopes to reflect the effects of range features on the hiker, namely that they cause him or her to take more steps along the hiking path.

The use of a range features correction factor may be particularly useful at ranges that have many different sector types. After the activity-specific area correction factor γ is modeled for a particular activity, the effects of terrain, vegetation, and other sector-specific features can be included using the range features correction factor ε. If adequate human behavior response modeling is available, the risk assessor might also use the range features correction factor to account for public awareness of UXO at a range.

2.2.1.5 Unexploded Ordnance Density (λ)

UXO density is estimated from data gathered during range sector sampling (see Section 3). Density must be examined from a three-dimensional perspective. Density is not merely a function of the UXO present but of the UXO available for contact. This means that the UXO density in an evaluated sector will vary, depending on the activity being modeled. The evaluation of P_E is activity-dependent, and UXO density for different activities – and corresponding intrusion depths – should be determined. Table 2 summarizes activity-dependent intrusion depths to be used in the risk analysis. Intrusion depths of 1, 4, and 10 feet are based on DoD guidance (DoD 1995).

UXO densities are specific to the receptor activity's intrusion depth and are calculated using Equation 12.

$$\lambda_j = \frac{n_j}{A_j} \qquad \text{Equation 12}$$

where,

λ_j	=	Depth-specific UXO density for activity *j*
n_j	=	Number of UXOs within maximum depth for activity *j*
A_j	=	Total area available for intrusion by activity *j*
j	=	Activity category, as follows: • *s* for surface density (UXO within 3 inches of surface) • *D*, where *D* is the intrusion depth for activity *j*

For example, if camping is the activity to be evaluated, the maximum intrusion depth is 4 feet. Therefore, λ_4 is calculated as the number of UXO within 4 feet of the ground surface divided by the surface area of the campsite. This activity-specific UXO density is then entered into the P_E equation. If construction is being evaluated, the maximum intrusion depth is 10 feet, and λ_{10} is calculated.

2.2.2 Conditional Probability of Detonation

Exposure to UXO does not always result in a detonation. Considering this, the likelihood that UXO exposure results in or coincides with a detonation is a critical factor in accurately modeling explosive safety risk. This factor is referred to as the conditional probability of detonation (P_D), which is a function of two factors, the minimum energy required to detonate the UXO (E_{min}) and the energy imparted to the UXO by various receptor activities (E_j).

Reactions such as explosions can be described as the sum of the reactants yielding the sum of the products of the reaction. Such a reaction requires an initial input of energy to bring the reactants together in the correct orientation for the reaction to proceed. The initial input energy is termed the energy of activation (E_a). It is, in essence, a barrier that must be overcome before the reaction occurs. This is true even for reactions that appear to be spontaneous. Once over the energy barrier, if sufficient energy is released, a reaction may become self-sustaining, with the energy released by one reacting specie providing the energy input for the next reacting specie.

For UXO, overcoming the E_a barrier is described as ignition or initiation, and it occurs when sufficient initiating force is imparted to the UXO (for example, temperature, shock, friction, magnetism, static electricity or lightning, and electromagnetic radiation) (Way 1997). Under normal conditions, fuzing systems, which consist of a series or combination of mechanical, electromechanical, electrical, or electronic devices, impart the necessary initiating force to an explosive to initiate detonation (Way 1997). Once the E_a barrier is overcome, the resulting thermal decomposition of the explosive is a self-sustaining exothermic reaction that goes rapidly to completion. Before the reaction can occur, however, there must be an input of energy to overcome E_a barrier. Only if sufficient energy – more than the E_a barrier – is imparted to a UXO can there be detonation. Because energy can physically change forms, it is possible to relate various forms of energy if one knows the efficiency of conversion and the relationship between the two forms of energy being measured. Therefore, the controlling factor in determining P_D is the minimum energy required to initiate the reaction (E_{min}), given the characteristics of the UXO or explosive.

The second factor in determining the probability of detonation is whether the receptor activities impart sufficient energy to initiate a detonation (E_j). Each receptor activity will have a different energy signature, both in terms of the quantity of energy imparted and in the area or volume affected by that energy. For example, a hiker imparts energy to the earth through the placement of his or her feet on the ground. In addition, the hiker imparts the energy from the muscular contractions involved in walking through the soles of his or her shoes. In turn, the total energy involved dissipates as it travels through an increasing volume of earth beneath the hiker. It is possible to determine the energy imparted by various receptor activities, enabling one to determine whether these activities are likely to impart enough energy to initiate an explosion. In this way, one can also compare the energies imparted by various activities. For example, a hiker places his or her weight over the area of his or her footprint, imparting one measure of energy. In contrast, a horseback rider exerts more pressure because of the combined weight of the horse and rider and the area of the horse’s hoof. The differing quantities of energy imparted by these two activities may result in a different probability of detonation.

In addition, various sources of energy can be assessed and combined into a single measure of imparted energy, allowing for assessment of multiple energy sources. For example, one could calculate the energy imparted by the bucket of a backhoe striking UXO. If this energy did not exceed the minimum energy required to cause detonation, it is reasonable to expect that an explosion would not occur. Likewise, if a clean-up involves detonating UXO in place, it should be possible to determine whether the detonation of a single piece of UXO would release sufficient energy to sympathetically detonate adjacent UXO.

Based on these two factors, the energy required to detonate the UXO and the sum of the energy imparted to the UXO by various receptor activities, P_D can be expressed as a ratio of the two terms:

$$P_D = \frac{\sum E_j}{E_{\min}} \qquad \text{Equation 13}$$

This function has a maximum value of 1. In other words, the function does not consider energy delivered in excess of the minimum energy required to detonate the UXO.

At present, limited data exist describing P_D values; however, data exist on the sensitivity of explosives, including sensitivity to impact and electrostatic forces. This information was a factor in manufacturing the explosives and in designing the munition; munitions designers determined how much energy would be required to initiate detonation when they designed the munition. Therefore, it should be possible to estimate the minimum energy that must be exerted to cause an explosion (E_{min}). It should also be possible to determine the energy imparted by various activities (E_j) that might occur in an area where UXO exists, so one should be able to determine whether these activities are likely to impart enough energy to initiate an explosion. In fact, information regarding the energy required to perform certain tasks is crucial to designing systems to perform those tasks, and one must know how much energy is required to move something in order to design a machine to move it. Standard references and methods exist for such assessments.

Because the SRE is an estimation of worst-case risk, the analysis should focus on the most sensitive explosive used in the types of UXO present on the range (typically, these will be the primary explosives used in fuzes) and the receptor whose activity imparts the greatest quantity of energy (a step that must include an assessment of the energy imparted by activities associated with the investigation or remediation of the range). In the absence of data to support specific estimates of P_D based on receptor activity, a default P_D value of 1 should be used to represent the worst-case scenario.

2.2.3 Consequences

Munitions (except for toxic chemical munitions) are devices used to deliver energy against a target in a quantity that the target cannot withstand. Although UXO detonation in proximity to a receptor may result in injury or death, this is not always the case. Therefore, the R3M considers *C*, which represents the conditional probability that a detonation results in injury to the receptor(s) in proximity to the UXO (with respect to humans, injury is defined a loss of a hand, arm, foot, leg, eyesight, or life). In the R3M, *C* is a function of two factors, the sum of the energy released by the detonation (D_i) and the maximum energy the receptor can withstand without injury (*Wj*). This function can be expressed as a ratio of these two factors:

$$C = \frac{\sum D_i}{W_j} \qquad \text{Equation 14}$$

This function has a maximum value of 1. In other words, the function does not consider energy delivered in excess of the maximum energy that the receptor can withstand without damage.

Explosions release energy by four primary mechanisms. Three of these mechanisms are considered to be primary mechanisms of energy transfer, and they include thermal transfer, overpressure, and fragmentation. The fourth mechanism is considered to be a secondary means of energy transfer; it is impact, or the energy transferred to the receptor as a result of the receptor being propelled into another object by the explosion (Way 1997).

In general, the energy imparted to a receptor is a function of two factors, net explosive weight (*NEW*) and the proximity of the receptor to the point of detonation. Effects experienced by the receptor include burns from the fireball caused by the thermal transfer mechanism, superficial soft tissue damage to severe trauma caused by the overpressure and impact mechanisms, and puncture wounds caused by fragmentation (Way 1997). The sum of these energy forms is the measurement of total energy released by the detonation. Depending on the receptor's sensitivity to various forms of energy, it may be necessary to evaluate these factors separately. For example, flammable receptors may require a detailed evaluation of thermal effects.

In any case, the energy released by the explosion is imparted to the receptor that caused the explosion. It is possible to determine the maximum amount of energy that a receptor such as a person or machine can withstand without injury (W_j). An existing body of data exists on this topic (in fact, this data is used to design munitions). Based on existing information regarding the amount of energy released by the detonation of particular explosives and the vulnerability of receptors to that energy, it is possible to assess whether a particular receptor will be injured if it imparts sufficient energy to cause detonation. Further, to more accurately predict the consequences of a UXO detonation, blast-dampening effects (such as overlaying soils) can be incorporated into the model, as could blast-enhancing effects (such as underwater conditions).

Because the SRE is focused on the estimation of risk for the MEI, it is appropriate to base C on the most lethal UXO type that receptor activities could detonate – the UXO that will impart the most energy to the receptor. This makes the worst-case assumption that a UXO detonation attributed to the MEI results in the maximum blast effect. For example, if receptor activities can cause detonation of more than one UXO type present in the evaluated range sector, C might be based on the UXO with the largest *NEW*. In the absence of data to support specific estimates of C, a default C value of 1 should be used to represent the worst-case scenario.

2.3 CONCEPTUAL EXPRESSION OF RISK

As discussed in Section 2.2, the risk from UXO (R) is characterized by three variables: the probability of encounter (P_E), conditional probability of detonation (P_D), and consequences of the detonation (C). The relationship between these variables is modified from Equations 2 and 9 and is presented below as Equation 15.

$$R = \left[1 - \left(1 - \frac{\varepsilon\gamma a}{A}\right)^{\lambda A}\right] \cdot \frac{\sum E_j}{E_{\min}} \cdot \frac{\sum D_i}{W_j} \qquad \text{Equation 15}$$

This relationship forms the basis of the SRE.

3.0 SAMPLING PATTERNS AND STRATEGIES

The derivation of P_E requires knowledge of ordnance density (λ). Density measurements from range sampling activities – often intrusive – can be used to derive estimates of density for each type of UXO within a particular range. Density is estimated based on data collected from randomly selected grids within a range in which surface and subsurface UXO are identified, typically using geophysical detection equipment and UXO recovery techniques.

The term "sampling" in the context of the R3M refers to measuring the number of items – in this case UXO – within a population subset to estimate the size of the entire population. For each range, sampling activities will attempt to identify the number of UXO within each grid to make ordnance-specific density estimates. Sample data is extrapolated to estimate the amount of each ordnance type within a specific area of interest, such as a sector.

Because each range presents different sampling challenges, a single, general sampling strategy may be used to minimize applicability problems. General sampling methods for the SRE and the DRE are the same, and the process of determining UXO density is critical for the successful application of both methodologies. The overall responsibility for the statistical sampling approach used lies with the project team. It is important that the sampling plan contain thorough documentation of the statistical approach used. The document should clearly state the power of the statistical tests used to determine the number of samples chosen and the uncertainties associated with the sampling design.

3.1 GENERAL SAMPLING METHODS AND TECHNIQUES

Selecting the sampling method most appropriate for determining UXO density requires an understanding of basic statistical sampling methods used to make such estimates. Three basic approaches are discussed in the following sections: simple random, stratified random, and systematic sampling methods (Deming

1950).

In addition to the methods presented in the following sections, risk assessors may wish to consider the use of Bayesian statistics, sequential statistics, and other knowledge-based statistical methods to derive sampling strategies. USACE has also developed several tools that can be used to estimate UXO density statistics at ranges or sectors, including an integrated computer program known as SiteStats/GridStats. It may be appropriate to use these or similar models to derive statistics for the R3M process.

3.1.1 Simple Random Sampling

With simple random sampling, sampling locations are selected randomly using computerized random number generators, random number tables, or other means. The probability that any one sampling location is selected is the same for all sampling locations, so each member of the population being sampled has an equal chance of being selected.

Sampling locations are usually determined by overlaying a base map with a grid. First, one pair of map coordinates (x and y) are selected randomly, and the grid is placed on the map at this location. Next, other pairs of random numbers are generated, and each of these locations is designated as a sampling location. This process is repeated until the desired number of sampling locations has been selected.

If large spatial variance exists, simple random sampling may not yield the desired resolution. Simple random sampling is useful at sites where little or nothing is known about the population heterogeneity or the distribution of items being sampled. Using the simple random sampling method has several drawbacks. If nonrandom spatial distribution exists within the population being sampled, simple random sampling may not provide the needed resolution to characterize the site.

3.1.2 Stratified Random Sampling

Stratified random sampling is a variation of simple random sampling. This method seeks to reduce the overall sample variance by sampling within relatively homogeneous subunits called strata. If heterogeneous conditions exist at the range, homogeneous strata are identified, such as impact areas, buffer zones, and areas of no known activity. More than one sample is collected within each stratum to estimate sampling error. Subpopulation differences between separate strata are demonstrated by analyzing the sampling variance within each stratum.

The proportion of the total number of samples allocated within each homogeneous stratum generally equals the proportion of the total area covered by all strata. Samples are located within each stratum randomly, using the simple random sampling approach.

3.1.3 Systematic Sampling

Systematic sampling is based on obtaining data from a population by measuring every k^{th} unit within the population. Random sampling plans are usually preferred over systematic sampling plans, because random sampling minimizes the subjective selection of sampling locations. If the objective of sampling is to determine the mean value of a population trait (such as ordnance type), it may be important to maintain objectivity by using a simple random scheme. However, the goal of UXO sampling is to determine the total population of UXO, not a particular UXO trait.

Systematic sampling has an advantage over random sampling in cases where uniform coverage of the entire population (or range) is important. Random sampling may limit sampling to selected areas; however, the systematic approach allows for complete coverage of areas with known impact.

3.2 EXAMPLE SAMPLING STRATEGY

One potential method of sampling range sectors for UXO includes a stratified systematic sampling strategy. This strategy takes advantage of the natural strata that exist within a range – the sectors – and has been used effectively in the past (SAIC 1995). Strata are predetermined based on historical range usage, as well as known or suspected areas of concern. Each stratum is gridded using the methods described in Section 3.3, with the initial grid node location determined randomly. This approach generally ensures adequate range coverage without applying a sampling bias within strata.

3.3 SAMPLE CELL CHARACTERISTICS

It is assumed that each piece of UXO on a range or within a stratum is independently located. In determining the quantity of sample cells, the goal is to maximize data capture while minimizing sampling program cost. In making sampling decisions, general approaches suggested by Deming (1950), EPA (1986), and the Michigan Department of Natural Resources (DNR) (1988) were considered.

Range or strata sizes between 100 and 5,000 acres are identified as breakpoints, and a reasonable percentage of each range or strata size is selected for sampling to estimate the quantity of UXO within the range or strata. The number of grid cells was determined after evaluating general EPA (1986) and Michigan DNR guidance (1988). Because each range and sector has a different geometry, specific grid cell spacing is not presented here; spacing must be determined on a range-by-range or sector-by-sector basis. Table 3 summarizes the minimum sampling area and number of grid cells that should be sampled for each range or strata category.

For example, consider a 15,000-acre range that must be evaluated (see Figure 3). The range contains two impact areas that were fired at from two firing points. The range is stratified into impact areas (200 acres), safety fans (4,500 acres), and other training areas (10,300 acres). From Table 3, a minimum of 10.6 acres must be sampled within the impact areas, a minimum of 16.8 acres must be sampled within the safety fans, and a minimum of 18.5 acres must be sampled within the training areas.

Using the minimum number of grids required from Table 3, the smallest grid size that can be sampled and still meet the minimum sample acreage requirements for each strata is controlled by the training area strata and is equivalent to 0.46 acres, or about 20,000 square feet. The sampling team might then choose a sample cell size of 140 by 140 feet. Each sampling cell is centered on a grid node, with the grid node spacing for each strata selected by trial and error until a suitable spacing is found that meets the minimum sample number requirements and maximizes area coverage. Grid spacing geometry may vary between range sectors. For this example, the selected grid spacing geometry is rectilinear (see Figure 3).

4.0 STREAMLINED RISK EVALUATION

The SRE is designed to provide the worst-case explosives safety risk estimates for a range's MEI receptor. Because the MEI receptor may be difficult to identify, certain default assumptions may be made in calculating risk estimates.

The following subsections discuss the evaluation of P_D, P_E, C, and R for the SRE.

4.1 PROBABILITY OF ENCOUNTER

For the SRE, P_E should be calculated using data for the MEI receptor. The following assumptions should be made for each variable that is part of the P_E estimation:

- Total area (A) is estimated based on the area of each sector that the MEI can reasonably be expected to enter while participating in a specific activity. For a sector-specific SRE, A is assigned this value and denoted as A_{MEI}.
- The area affected by a receptor (a) is estimated based on the largest affected area calculated using Equations 10 or 11. If a is larger than A, the value of a is set to A. The variable is assigned this value and denoted as a_{MEI}.
- The activity-specific correction factor (γ) is assigned a value of 1 for the SRE; it does not affect P_E.
- The range features correction factor (ε) is assigned a value of 1 for the SRE; it does not affect P_E.
- From data obtained during range sampling activities, UXO density (λ) is assigned the lesser of (1) the density of the densest grid sampled within A_{MEI} or (2) the 85 percent upper-confidence limit of the mean density estimate for A_{MEI}. The density, denoted as λ_{MEI}, includes all UXO to the activity-specific intrusion depth.

4.2 CONDITIONAL PROBABILITY OF DETONATION

For the SRE, the worst-case P_D value attributable to the MEI activity is used to calculate R. This approach assumes that initiating forces attributable to the MEI are sufficient to represent the worst-case scenario. This term is denoted as $P_{D,max}$. As discussed in Section 2.2.3, P_D should be determined based on the ratio of the energy imparted by various receptor activities and the energy required to detonate UXO. In the absence of data to support specific estimates of $P_{D,max}$ based on MEI activity, a default $P_{D,max}$ value of 1 should be used to represent the worst-case scenario.

When ecological receptors represent the MEI, P_D shall be determined based on intrusion depth of the receptor or species attributed with imparting the initiating force. This intrusion depth shall be determined based on the normal expected habits of the species.

4.3 CONSEQUENCES

For the SRE, the worst-case C value applicable to the evaluated sector is used to calculate R. This approach assumes that all UXO detonations associated with the MEI result in the maximum blast effect. This term is denoted as C_{max}. In the absence of data to support specific estimates of C, a default C_{max} value of 1 should be used to represent the worst-case scenario.

4.4 RISK

After all risk variables have been defined, R is calculated. For the SRE, Equation 15 is modified to ensure that risk is estimated in a highly conservative manner. The modified equation is shown as Equation 16.

$$R = \left[1 - \left(1 - \frac{a_{MEI}}{A_{MEI}}\right)^{\lambda_{MEI} A_{MEI}}\right] \cdot P_{D,\max} \cdot C_{\max} \qquad \text{Equation 16}$$

where,

R_{MEI}	=	Risk estimate for MEI receptor
a_{MEI}	=	Area impacted by MEI receptor ($\leq A$) (acre)
A_{MEI}	=	Area within all sectors in which MEI receptor participates in an activity (acre)
λ_{MEI}	=	Greater of the 85-percent upper confidence UXO density within A_{MEI}, or the UXO density of the most dense grid sampled within A_{MEI} (acre^{-1})
$P_{D,\max}$	=	Highest P_D value associated with UXO in A_{MEI}
$C_{\max}$	=	Highest C value associated with UXO in A_{MEI}

Equation 16 can be used to derive the deterministic risk estimate for the MEI receptor. This deterministic MEI receptor risk estimate is then compared to the threshold risk values to evaluate risk acceptability (see Section 4.5).

This risk calculation provides an estimate for a specific entry activity at a range sector. Risk models used by EPA for exposure to hazardous materials estimate excess cancer risks based on lifetime exposures. To be consistent with that approach, Equation 16 can be modified to estimate lifetime risk (LR) as shown below:

$$LR = \frac{R_{MEI} \cdot EF \cdot ED}{LT} \qquad \text{Equation 17}$$

where,

LR	=	Lifetime risk
EF	=	Entry frequency
ED	=	Entry duration
LT	=	Lifetime

4.5 RISK-BASED RANGE DESIGNATION

When appropriate variable values are determined and used in the R3M equations, risk estimates are derived for the R3M MEI receptor. Risk estimates are then compared to threshold risk values to determine whether the range poses an unacceptable risk to safety, health, or the environment.

In carcinogenic chemical risk assessment, EPA accepts a threshold risk of 1×10^{-4} to 1×10^{-6} excess cancer cases (EPA 1989). In a 1980 decision, the U.S. Supreme Court identifies as “significant” a 2 in 100

(2×10^{-2}) probability of death from regular inhalation of gasoline vapors. The Court further identifies as "clearly insignificant" a 1 in 1 billion (1×10^{-9}) probability of cancer-caused death from taking a drink of chlorinated water (Supreme Court Reporter 1980).

Based in part on this U.S. Supreme Court decision, the U.S. Army Technical Center for Explosives Safety (USATCES) defines "tolerable probability" as "any hazard whose probability of occurrence produces a level of risk that an average, reasonably prudent person would accept without concern for the consequences, from a position of foresight, not hindsight." USATCES quantifies this tolerable probability as 1×10^{-9} (Proper 1994).

Using the approach taken by EPA (1989), the U.S. Supreme Court (Supreme Court Reporter 1980), and USATCES (Proper 1994), it is reasonable to set a threshold for unacceptable risk at a level between 1×10^{-4} and 1×10^{-9}. For the SRE, a risk threshold of 1×10^{-6} is proposed.

The R_{MEI} value determined during the SRE represents worst-case, quantitative level of explosives safety risk posed by the evaluated sector, and it will assist the risk manager in determining the next logical step in the range rule process for that sector. SRE designations and recommended further actions are described below.

- For sectors where R_{MEI} exceeds 1×10^{-4}, the risk manager may recommend that a DRE be conducted for the sector.

- For sectors where R_{MEI} is between 1×10^{-6} and 1×10^{-4}, the risk manager may recommend evaluating accelerated responses that may reduce risk to an acceptable level.

- For sectors where R_{MEI} is less than 1×10^{-6}, the risk manager may recommend that the range sector be directed to the close-out process.

5.0 DOCUMENTATION

For ranges evaluated using the SRE, a report will be generated to document the process and recommend range close-out, consideration of an AR, or further risk evaluation using the DRE. The SRE report will contain data obtained during the SRE process and will identify all data sources necessary to substantiate the SRE result. A sample SRE report table of contents is provided in Appendix A.

REFERENCES

Deming, W.E. 1950. *Some Theory of Sampling*. Dover Publications, Inc. New York, New York.

Hill, S.A., F.A. Zafran, J. Skibinski, A.N. Unger, M. Lustik, and L.G. Cain. "Risk Assessment Methodology for Use In Managing Sites Containing Unexploded Ordnance." *Proceedings of UXO Forum 1996*. Williamsburg, Virginia. March.

Michigan Department of Natural Resources (DNR). 1988. "How Clean is Clean?" Waste Management Division. May.

Mulvihill, R.J., K. Kruk, M. Keefe, J. Sperka, and A. Pedersen. 1996. "Unexploded Ordnance Risk Assessment Framework." *Proceedings of UXO Forum 1996*. Williamsburg, Virginia. March.

National Academy of Sciences (NAS). 1983. *Risk Assessment and the Federal Government: Managing the Process*. National Academy Press. Washington, DC.

PRC Environmental Management, Inc. (PRC EMI). 1995. Letter Regarding Unexploded Ordnance Risk Assessment. From Michael Keefe, Environmental Engineer. To Gerard Snyder, Program Manager, Naval Explosives Ordnance Disposal Technology Division. October 31.

Proper, K.W. 1994. "A Mathematical Model for a Quantitative Risk Matrix." U.S. Army Defense Ammunition Center and School. Savannah, Illinois. May.

QuantiTech, Inc. (QuantiTech). 1994. "OEW Site Risk Mitigation Prioritization." Final Report. Technical Report 93R004vD. June 1.

Riggs, J.L., and A. Fanning. 1996. "Ordnance and Explosives Cost-Effectiveness Risk Tool (OECert)." *Proceedings of UXO Forum 1996*. Williamsburg, Virginia. March.

Science Applications International Corporation (SAIC). 1995. "Fort George G. Meade BRAC Parcel UXO Survey and Data Analysis." Draft Report. September.

Supreme Court Reporter. 1980. *Industrial Union Department, AFL-CIO, Petitioner v. American Petroleum Institute et al., Ray Marshall, Secretary of Labor, Petitioner, v. American Petroleum Institute et al.* 448 U.S. 607, 65 L. 2nd Ed. 1010, NOS 78-911, 78-1036. Argued October 10, 1979. Decided July 2, 1980. Page 2876.

U.S. Department of Defense (DoD). 1995. "DoD Ammunition and Explosives Safety Standards." DoD 6055.9-STD. March.

U.S. Department of Defense (DoD). 1997. Draft Proposed Military Range Rule. 61 Federal Register 6588. Vol. 61, Ed. 35. February 21, 1996. Internet Revision April 23, 1997.

U.S. Environmental Protection Agency (EPA). 1986. "Test Methods for Evaluating Solid Waste." Office of Solid Waste and Emergency Response (OSWER). SW-846. November.

U.S. Environmental Protection Agency (EPA). 1989. "Risk Assessment Guidance for Superfund (RAGS): Human Health Evaluation Manual Part A." OSWER Directive 9285.701A.

U.S. Environmental Protection Agency (EPA). 1996. "Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments." Environmental Response Team. Edison, NJ. EPA/630/R-95/002B.

Way, Ralph. 1997. "Analysis of R3M Risk Assessment Methodology Variables: Probability of Detonation and Consequence". 15 September.

FIGURES

FIGURE 1
RANGE RULE PROCESS

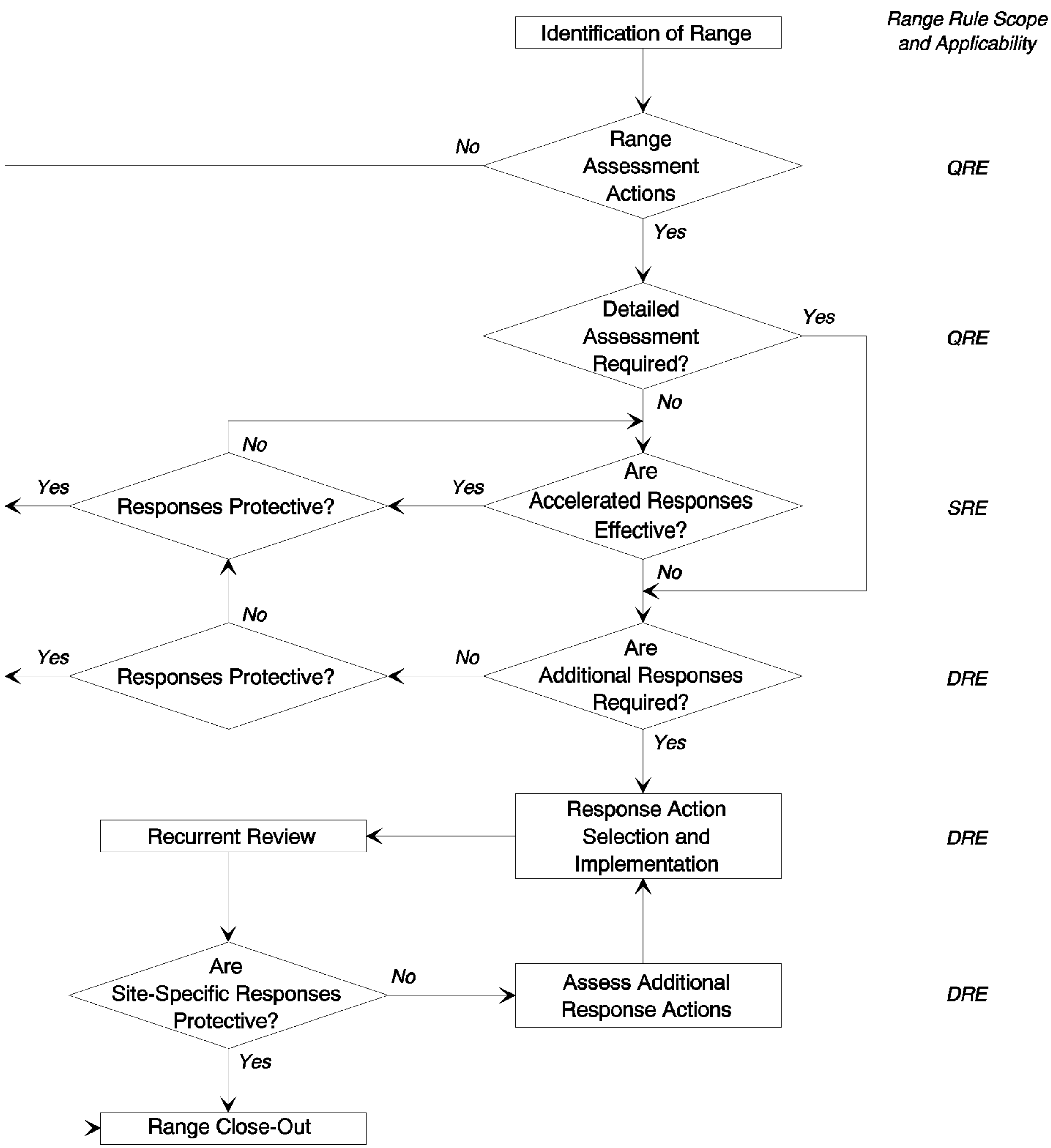


FIGURE 2
P_E FOR VARIOUS a AND λ AT A NORMALIZED RANGE

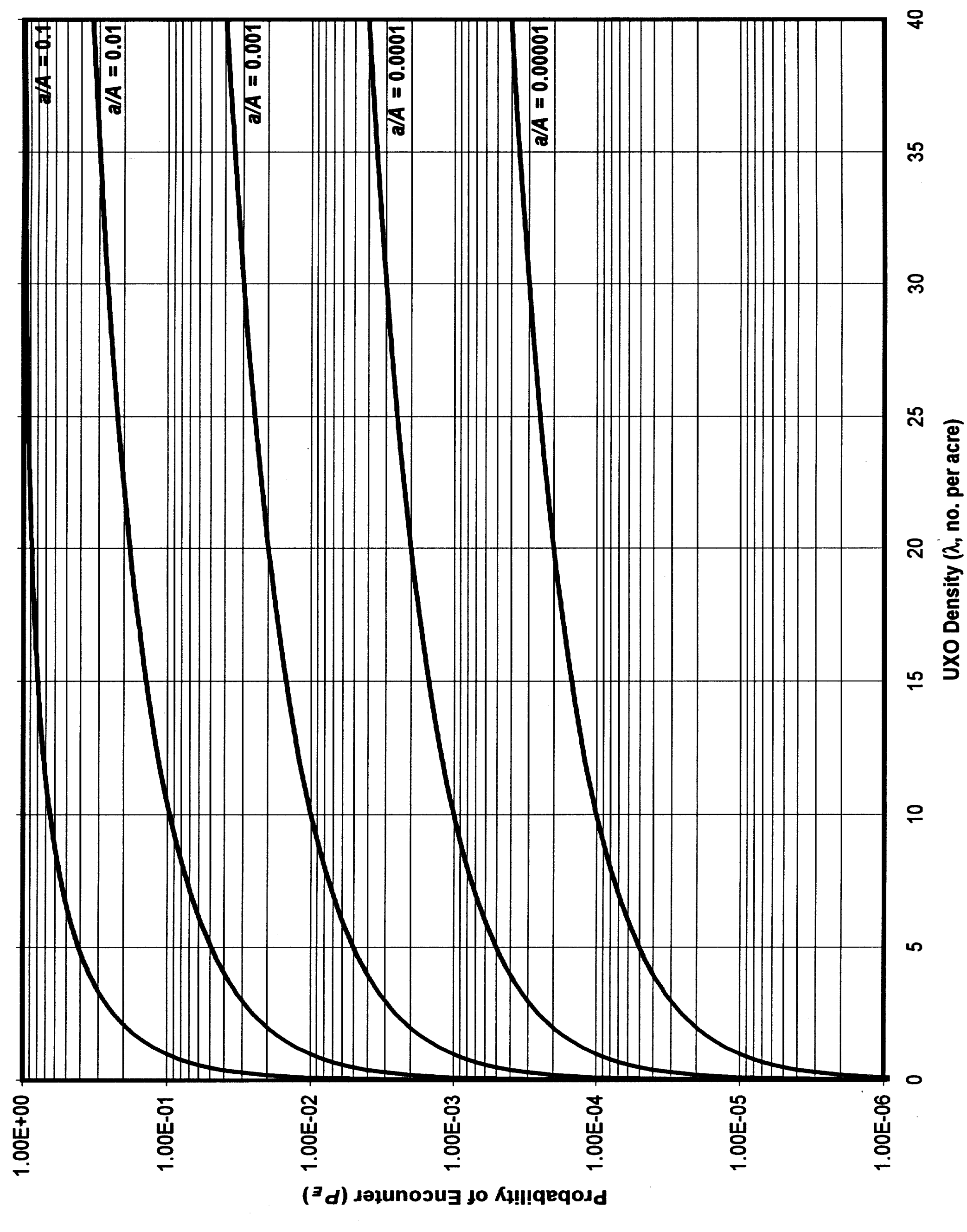
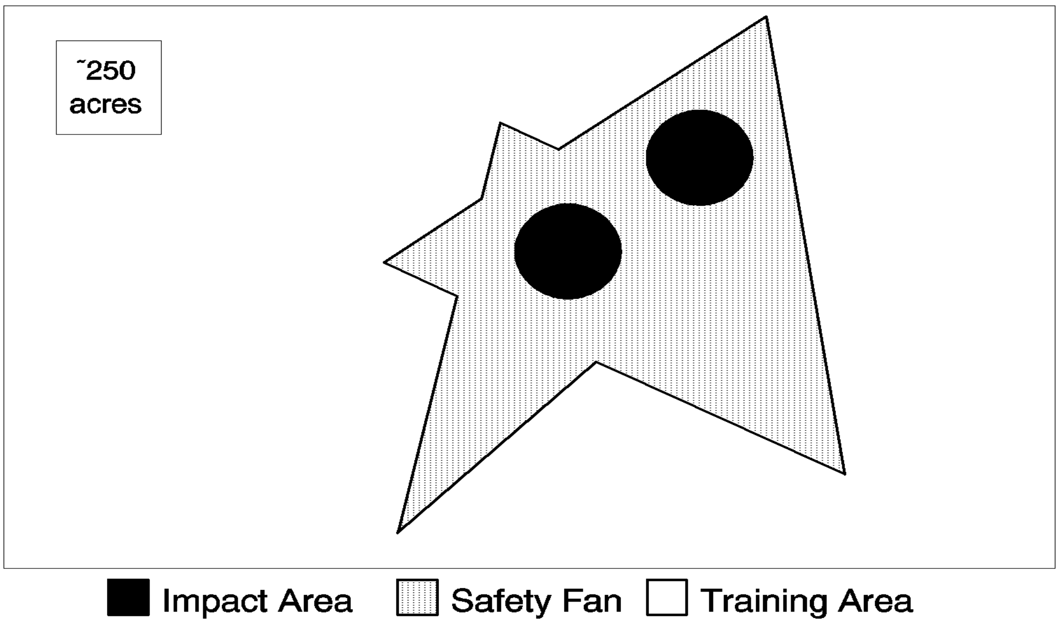
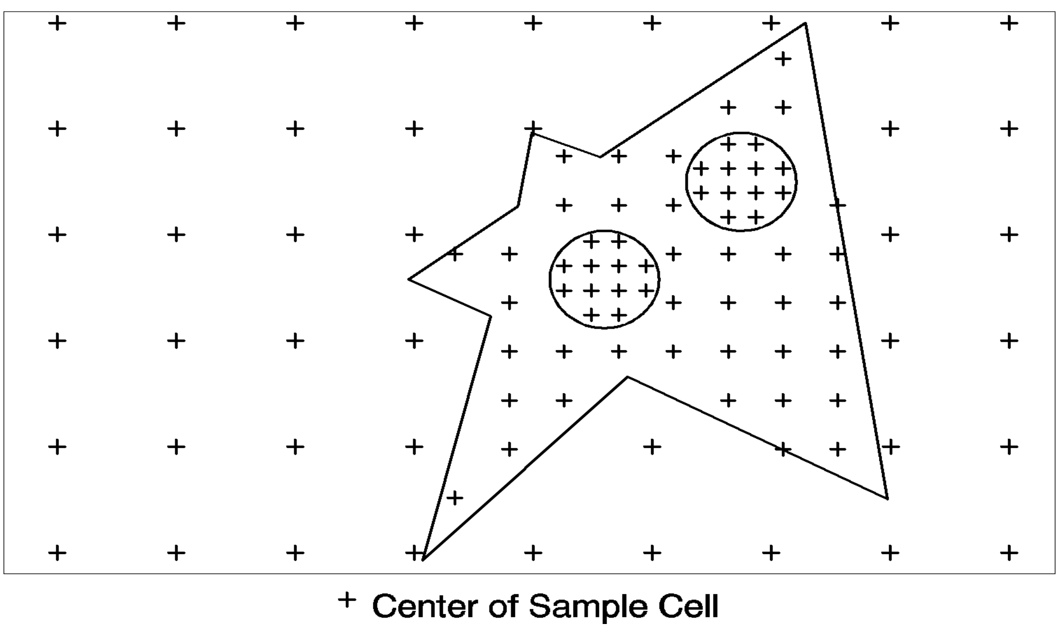


FIGURE 3
EXAMPLE RANGE SAMPLING PLAN





TABLES

TABLE 1
ACTIVITIES IDENTIFIED BY EXISTING RISK MODELS

Activity	***OECert*** [a]	***Fort Meade*** [b]	***NAVEOD-TECHDIV*** [c]
Distance-Based Activities			
Hiking or walking	X	X	X
Jogging or running	X	X	X
Short cut taking	X		
Hunting	X	X	X
Horseback riding	X		
Mountain biking	X		X
Motor biking	X		
Off-road vehicling	X		X
Swimming or wading	X		X
Surveying	X		
Site-Based Activities			
Camping	X		X
Children playing	X		X
Metal detecting	X		
Picnicking	X		
Fishing	X	X	
Agriculture or crop farming	X		X
Ranching	X		
Archaeology	X		X
Construction	X		X
On-post working		X	
Unrestricted activity			X

Notes:

a Data summarized from QuantiTech (1994)
b Data summarized from SAIC (1995)
c Data summarized from PRC EMI (1995)

TABLE 2
ACTIVITY-DEPENDENT INTRUSION DEPTHS

Activity	***Intrusion Depth (feet)***
Distance-Based Activities	
Hiking or walking	1
Jogging or running	1
Trespassing	1
Hunting	1
Horseback riding	1
Mountain biking	1
Motor biking	1
Off-road vehicling	4
Swimming or wading	4
Surveying	1
Site-Based Activities	
Camping	4
Children playing	4
Metal detecting	1
Picnicking	1
Fishing	1
Agriculture or crop farming	4
Ranching	1
Archaeology	10
Construction	10
On-post working	1
Unrestricted activity	10

Source: Modified from DoD 1995; PRC EMI 1995; Quantitech 1994

TABLE 3
SAMPLE CELL SIZE AND SPACING

Strata Area (SA) (acres)	***Minimum Sampling Area (acres)***	***Minimum No. of Grid Cells***
Less than 5	Entire range	Not applicable
5 to 100	5	10
100 to 1,000	$2 \ln (SA)$	15
1,000 to 5,000	$2 \ln (SA)$	25
More than 5,000	$2 \ln (SA)$	40

APPENDIX A

SAMPLE TABLE OF CONTENTS FOR STREAMLINED RISK EVALUATION REPORT

(2 Pages)

STREAMLINED RISK EVALUATION

PROJECT NAME
PROJECT LOCATION

CONTENTS

CONTENTS (Continued)